Structure of ^{8}B and astrophysical S_{17} factor in Skyrme Hartree-Fock theory

S. S. Chandel and S. K. Dhiman
Department of Physics, Himachal Pradesh University, Shimla 171005, India

R. Shyam
Saha Institute of Nuclear Physics, 1/AF, Bidhan Nagar, Kolkata 700 064, India
(Received 20 June 2003; published 24 November 2003)

We investigate the ground-state structure of ^{8}B within the Skyrme Hartree-Fock framework where spin-orbit part of the effective interaction is adjusted to reproduce the one-proton separation energy of this nucleus. Using same set of force parameters, binding energies and root mean square radii of other light *p*-shell unstable nuclei ^{8}Li, ^{7}B, ^{7}Be, and ^{9}C have been calculated, where a good agreement with corresponding experimental data is obtained. The overlap integral of ^{8}B and ^{7}Be wave functions has been used to determine the root mean square radius of the single proton in a particular orbit and also the astrophysical *S* factor (S_{17}) for the $^{7}\mathrm{Be}(p,\gamma)^{8}\mathrm{B}$ radiative capture reaction. It is found that the asymptotic region (distances beyond 4 fm) of the *p*-shell single-proton wave function contributes more than half to the calculated value (4.76 fm) of the corresponding single-particle root mean square radius. The value of S_{17} is determined to be 22.0 eV b which is in good agreement with the recommended value for the near zero energy S_{17} of $19.1^{+4.0}_{-1.0}$ eV b.

DOI: 10.1103/PhysRevC.68.054320 PACS number(s): 21.60.Jz, 21.10.Ft, 21.65.+f, 26.65.+t

I. INTRODUCTION

Studies involving rare neutron-rich and proton-rich isotopes are currently at the forefront of the nuclear physics research. Experiments [1–3] performed with beams of nuclei far from the beta stability (NFABS) line have revealed many features of these systems which are not present in their stable counterparts. For example, some NFABS having very small particle separation energies are very large in their radial dimensions (they are also called halo nuclei); their radii are not governed by the usual $r_0A^{1/3}$ (with $r_0=1.20$ and *A* being the mass of the nucleus) rule. The discovery of these nuclei underlines the necessity of revising the traditional picture of nuclear structure in important ways since away from the β stability nuclear dynamics are characterized by a variety of new features not present in stable nuclei. In the halo region the quantum dynamical effects play a crucial role in distribution of the nuclear density in the zone of very weak binding.

Proper knowledge of the structure of ^{8}B nucleus is important for several reasons. This nucleus perhaps is the most likely candidate for having a proton halo structure, as its last proton has a binding energy of only 137 keV. ^{8}B produced via $^{7}\mathrm{Be}(p,\gamma)^{8}\mathrm{B}$ reaction in the Sun is the source of high energy neutrinos which are detected in Sudbury Neutrino Observatory (SNO), Kamiokande, and Homestake experiments [4–6]. Therefore, accurate determination of the cross section of this reaction at relative energies corresponding to solar temperatures (about 20 keV) is very important to the solar neutrino issue. In this energy region, the cross section $\sigma_{p\gamma}(E_{\mathrm{c.m.}})$ [which is usually expressed in terms of the astrophysical $S_{17}(E_{\mathrm{c.m.}})$ factor] of the $^{7}\mathrm{Be}(p,\gamma)^{8}\mathrm{B}$ capture reaction is directly proportional to the high energy solar neutrino flux. A better knowledge of S_{17} is, therefore, important to improve the precision of the theoretical prediction of ^{8}B neutrino flux from present and future solar neutrino experiments.

$^{7}\mathrm{Be}(p,\gamma)^{8}\mathrm{B}$ reaction has been studied extensively both theoretically as well as experimentally [7–13]. S_{17} is determined either by direct measurements [14] or by indirect methods such as Coulomb dissociation [15] of ^{8}B on heavy targets and transfer reactions in which ^{8}B is either the residual nucleus or the projectile nucleus [16–19]. Efforts have also been made to calculate the cross section of this reaction within the framework of the shell model and the cluster model [20–22]. The key point of these calculations is the determination of the wave functions of ^{8}B states within the given structure theory.

Aim of the present study is to investigate the structure of ^{8}B in the framework of the Skyrme Hartree-Fock (SkHF) model which has been used successfully to describe the ground-state properties of both stable [23–26] as well as exotic nuclei [27–30]. The phenomena of nuclear skin and halo have been studied in medium mass and heavy nuclei [29,30] within the Skyrme-Hartree-Fock-Bogoliubov method using the SLy4 Skyrme force [31]. The SkHF method with density-dependent pairing correlation and SLy4 interaction parameters has been successful in reproducing the binding energies and root mean square (rms) radii [29] in the light neutron halo nuclei ^{6}He, ^{8}He, ^{11}Li, and ^{14}Be.

We solve spherically symmetric Hartree-Fock (HF) equations with SLy4 [31] Skyrme interaction which has been constructed by fitting to the experimental data on radii and binding energies of symmetric and neutron-rich nuclei. This has also been used in Ref. [30] to study the phenomenon of shape coexistence in semimagic isotopes of Mg, S, and Zr nuclei. In our calculations pairing correlations among nucleons have been treated within the BCS pairing method. We have, however, renormalized the parameter of the spin-orbit term of the SLy4 interaction so as to reproduce the experimental binding energy of the last proton in the ^{8}B nucleus. A check on our interaction parameters was made by calculating binding energies and rms radii of ^{7}Be, ^{7}B, ^{8}Li, and ^{9}C nuclei

 ©2003 The American Physical Society

with the same set where a good agreement is obtained with corresponding experimental data. We calculate the rms radii for matter, neutron, and proton distributions for ^{8}B. Using the overlap integral of HF wave functions for ^{7}Be and ^{8}B ground states, the rms radius of the valence p-shell proton in this nucleus has been determined, which is expected to provide information about the proton halo structure in ^{8}B. The overlap integral has also been used to calculate the astrophysical S_{17} factor.

The paper is organized in the following way. In Sec. II we present the short description of the method of our calculations. Sec. III contains our results and their discussions. Summary and conclusions of our study are given in Sec. IV.

II. METHOD OF CALCULATIONS

In the Skyrme Hartree-Fock formalism binding energies, densities, and single-particle wave functions are obtained from a local energy functional. Skyrme force parameters are determined empirically by fitting the properties of the nuclear matter, of stable nuclei, and of neutron star [31]. Microscopically, the Skyrme functional corresponds to an expansion of the nuclear interaction up to the first order in momentum transfer [23]. The ground-state properties of nuclei are derived self-consistently from the total energy functional of the nucleus which is given by [24]

$$E = E_{KE} + E_{sk} + E_{sk,ls} + E_{Coul} + E_{Coul,exch} + E_{pair} - E_{\mathrm{c.m.}}, \tag{1}$$

where E_{KE} is the kinetic energy functional, E_{sk} is the Skyrme functional, $E_{sk,ls}$ is the spin-orbit functional, E_{Coul} is the Coulomb energy functional, $E_{Coul,exch}$ is Coulomb exchange energy term, E_{pair} is the pairing energy, and $E_{\mathrm{c.m.}}$ is the center of mass (c.m.) correction term. The first five terms of Eq. (1) are given by

$$E_{KE} = 4\pi \sum_{q\in p,n} \int_0^\infty drr^2 \frac{\hbar}{2m_q}\tau_q, \tag{2}$$

$$\begin{aligned} E_{sk}(\rho,\tau) = {} & 4\pi\int_0^\infty drr^2\left(\frac{b_0}{2}\rho^2 + b_1\rho\tau - \frac{b_2}{2}\rho\nabla^2\rho + \frac{b_3}{3}\rho^{\beta+2}\right) \\ & - 4\pi\sum_{q\in p,n}\int_0^\infty drr^2\left(\frac{b_0'}{2}\rho_q^2 + b_2'\rho_q\tau_q - \frac{b_1'}{2}\rho_q\nabla^2\rho_q \right. \\ & \left. - \frac{b_3'}{3}\rho^\beta\rho_q^2\right), \end{aligned} \tag{3}$$

$$E_{sk,ls}(\rho,J) = -4\pi\int_0^\infty drr^2(b_4\rho\,\nabla J + b_4'\rho_q\,\nabla J_q), \tag{4}$$

$$E_{Coul}(\rho_p) = \frac{1}{2}e^2\int d^3rd^3r'\rho_C(r)\frac{1}{|r-r'|}\rho_C(r')r, \tag{5}$$

$$E_{Coul,exch}(\rho_p) = -\frac{3}{4}\left(\frac{3}{\pi}\right)^{1/3} 4\pi\int_0^\infty drr^2\rho_p^{4/3}(r), \tag{6}$$

where $q\in\{p,n\}$ is the isospin label for proton and neutron. In Eq. (2) τ_q is the kinetic energy density (see, e.g., Ref. [24] for its definition). In Eqs. (3) and (4) ρ_p is proton density while ρ is the sum of proton and neutron densities, and J is the sum of neutron and proton spin densities (denoted individually for neutron and proton by J_q). It may be noted that an additional coefficient b_4' has been introduced in the spin-orbit term of the energy functional [Eq. (4)].

The pairing energy function is introduced as [32]

$$E_{pair} = -\sum_{q\in p,n} G_q\left[\sum_{\alpha\in q}\sqrt{v_\alpha(1-v_\alpha)}\right]^2. \tag{7}$$

In Eq. (7) G_q are pairing matrix elements which are taken to be constant for $q\in p,n$ (G_q=29/A MeV for each case) and the occupation probability of state α is denoted by v_α. The BCS equations for the pairing weights are obtained by varying the energy functional with respect to v_α. This yields the standard BCS equations for the case of a constant pairing force. The occupation weights are then given by

$$v_\alpha^2 = \frac{1}{2}\left[1 - \frac{(\epsilon_\alpha - \epsilon_{F,\alpha})^2}{(\epsilon_\alpha-\epsilon_{F,\alpha})^2 + \Delta_q^2}\right], \tag{8}$$

where ϵ_α is the single-particle energy of the given orbit. The pairing gap Δ_q and the Fermi energy $\epsilon_{F,q}$ are obtained by the iterative solution of the gap equation and the particle number condition

$$\frac{\Delta_q}{G_q} = \sum_{\alpha\in q}\sqrt{v_\alpha(1-v_\alpha)}, \tag{9}$$

$$A_q = \sum_{\alpha\in q} v_q, \tag{10}$$

where A_q is the desired number of proton and neutrons. This treatment is also called constant force approach.

In the Hartree-Fock method the mean field localizes the wave functions, which breaks the translational invariance. This causes spurious contribution from the c.m. motion to the observables. One way of removing this problem is to use the projection-after-variation method in which the zero-point energy of nearly harmonic oscillation of the c.m. is subtracted from the mean-field energy functional. This correction term is written as

$$E_{\mathrm{c.m.}} = \frac{\langle P_{\mathrm{c.m.}}^2\rangle}{2Am}, \tag{11}$$

where m is the average mass of nucleons and $P_{\mathrm{c.m.}}=\Sigma_i\,\hat{p}_i$ is the total angular momentum operator in the c.m. frame, which projects a state with good total angular momentum out of the given mean-field state. $P_{\mathrm{c.m.}}^2$ is written as

$$\langle P^2_{\text{c.m.}}\rangle = \sum_\alpha v_\alpha^2 \langle\phi_\alpha|\hat{p}^2|\phi_\alpha\rangle - \sum_{\alpha\beta}[v_\alpha v_\beta(v_\alpha v_\beta + u_\alpha u_\beta)] \times(|\langle\phi_\alpha|\hat{p}|\phi_\beta\rangle|^2), \tag{12}$$

where $u_{\alpha(\beta)}=\sqrt{1-v^2_{\alpha(\beta)}}$. This correction, however, is computed after variation (i.e., *posteriori*). This prescription improves the total energy, but it is not clear that it improves the wave functions.

Spherical symmetric single-particle wave functions for a nucleus are given in expansion basis by

$$\psi_\alpha(r) = \phi_\alpha(r) \times Y_{l_\alpha j_\alpha m_\alpha}(\theta,\phi), \tag{13}$$

where the spinor-spherical harmonics are given by $Y_{l_\alpha j_\alpha m_\alpha}(\theta,\phi)$ and $\phi_\alpha(r)$ represents the radial wave function. Various densities used in Eqs. (2)–(8) are defined as

$$\rho_q(r) = \sum_{\alpha\in q} N_\alpha |\psi_\alpha(r)|^2, \tag{14}$$

$$\tau_q(r) = \sum_{q\in q} N_\alpha |\nabla\psi_\alpha(r)|^2, \tag{15}$$

$$\nabla J_q(r) = -i\sum_{\alpha\epsilon q} N_\alpha \nabla \psi_\alpha(r)^+ \cdot \nabla \times \sigma\psi_\alpha(r). \tag{16}$$

In Eqs. (14)–(16), N_α represents the desired proton or neutron number which is equal to v^2_α (BCS occupation probabilities of orbitals). Densities without an isospin label are $\rho=\rho_p+\rho_n$, $\tau=\tau_p+\tau_n$, and $J=J_p+J_n$.

III. RESULTS AND DISCUSSIONS

A. Binding energies, radii, and density distributions

The values of various parameters of the SLy4 Skyrme effective interaction as used in our calculations are $t_0=-2488.91$, $t_1=486.82$, $t_2=-546.39$, $t_3=13\,777.0$, $b_4=61.5$, $x_0=0.83$, $x_1=-0.34$, $x_2=-1.00$, $x_3=1.35$, and $\beta=\frac{1}{6}$. The values of b_i and b_i' parameters in Eqs. (3) and (4) have been obtained from t_i and x_i by using the relations given in Appendix A of Ref. [30]. We use two-body zero range spin-orbit interaction by taking $b_4'=b_4$ combination [25]. These parameters are the same as those given in Refs. [29,30] except for the spin-orbit term which has been renormalized by taking $b_4=37.42$ so as to reproduce the single-proton separation energy of ^{8}B. The adjusted value of the parameter b_4 is smaller than its original value of 61.50. This observation is in line with the weakening of the spin-orbit interaction in light drip line nuclei noted in Ref. [33]. In the following, the force with renormalized b_4 will be referred to as TH1 and that with the original b_4 as TH2.

TABLE I. The comparison of theoretical binding energies for various nuclei calculated in self-consistent SkHF method with experimental data. TH1 and TH2 represent theoretical results obtained with modified and original values of the (b_4) parameter of the SLy4 Skyrme force, respectively.

Nucleus	BE(MeV)		
	Expt.	Theor.	
		TH1	TH2
^{7}Be	37.601	37.561	39.780
^{7}B	24.720	24.262	25.931
^{8}Li	41.278	41.034	44.098
^{8}B	37.379	37.739	40.677
^{9}C	39.716	37.035	37.416

With the same set of force parameters we have calculated total binding energies and rms radii of light unstable nuclei ^{8}Li, ^{8}B, ^{7}B, ^{7}Be, and ^{9}C. Results for binding energies are presented in Table I where the corresponding experimental values are also shown [34]. Binding energies calculated with TH1 and TH2 forces are shown in third and fourth columns of this table, respectively. It is clear that with the renormalized b_4, our calculations reproduce the experimental binding energies of these nuclei to the extent of 98%. Furthermore, the single-neutron separation energy S_n for ^{8}B as calculated with the same force parameter set is 13.47 MeV which is in good agreement with the corresponding experimental value of 13.02 MeV.

The rms radii for matter (r_m), neutron (r_n), and proton (r_p) distributions are presented in Table II for all the five isotopes. Also shown in this table are the matter, neutron, and proton radii (under the column "expt.") extracted by methods in

TABLE II. Rms mass (r_m), proton (r_p), and neutron (r_n) radii for various nuclei. TH1 and TH2 represent the theoretical results obtained with modified and original values of the (b_4) parameter of the SLy4 Skyrme force, respectively. Also shown, under the column "Expt.,"are the values of corresponding radii extracted by fitting the reaction or interaction cross sections by different theoretical methods as discussed in the text. We have defined $r_i=\langle r_i^2\rangle^{1/2}$.

Nucleus	Rms radii (fm)								
	Expt.			Theory					
				TH1			TH2		
	r_m	r_p	r_n	r_m	r_p	r_n	r_m	r_p	r_n
^{7}Be	2.33±0.02			2.49	2.63	2.29	2.32	2.46	2.12
^{7}B				2.86	3.18	1.84	2.73	3.01	1.87
^{8}Li	2.37±0.02	2.26±0.02	2.44±0.02	2.54	2.29	2.67	3.01	2.98	3.02
^{8}B	2.55±0.08	2.76±0.08	2.16±0.08	2.57	2.73	2.27	2.84	2.96	2.73
	2.43±0.03	2.49±0.03	2.33±0.03						
^{9}C	2.42±0.03			2.59	2.77	2.20	2.13	2.32	1.67

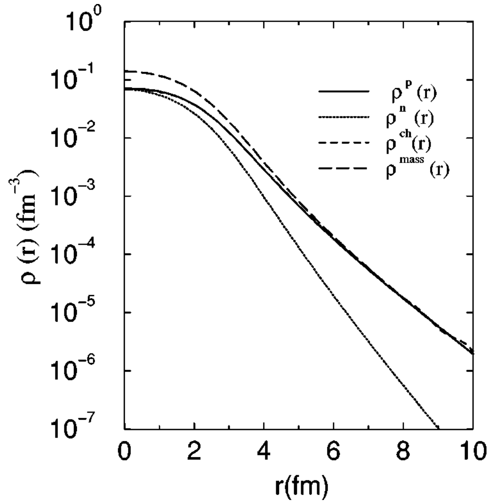

FIG. 1. Density distribution $\rho(r)$ for protons, neutrons, charge, and mass in ^{8}B nucleus calculated with SkHF method.

which measured reaction (or interaction) cross sections are fitted by theoretical models having them as input parameters. These numbers are taken from Ref. [2] for ^{7}Be, from Ref. [35] for ^{8}Li, from Refs. [36,35] for ^{8}B, and from Ref. [37] for ^{9}C. The quantities listed under "theory" column are the results of our calculations. Here r_m is obtained by summing the average of proton and neutron radii in every orbit weighted with occupation probabilities. We see that for all the isotopes r_m calculated with the modified b_4 parameter is in better agreement with the corresponding values listed under the expt columns as compared to that calculated with the original b_4.

In Fig. 1, we show distributions of matter, charge, neutron, and proton densities (in the units of fm^{-3}) in the coordinate space. The density distribution has been obtained by folding the HF results for proton and neutron densities with the intrinsic charge density distribution of nucleons in Fourier space by transforming the densities to form factors. In actual calculations of the nuclear charge density, the c.m. correction effects are taken into account by unfolding the spurious vibrations of the nuclear c.m. in harmonic approximation [as is done in Eq. (11) for the zero-point energy]. We note that nuclear charge and proton densities differ very slightly from each other. The key point of this figure is that the neutron and proton densities differ quite a bit from each other for distances larger than 3 fm, where the proton density develops a long tail. This is reminiscent of the situation in the neutron halo nuclei where the neutron density distribution has a long tail [3]. This observation supports the existence of a proton halo structure in ^{8}B.

B. Valence proton radius in ^{8}B and astrophysical S_{17} factor

To begin our discussions in this section we define a overlap function of the bound state wave functions of two nuclei B and A, where B=A+p (p represents a proton). For the case of interest in this paper A=^{7}Be and B=^{8}B. We can write a formal expression for this overlap function as

$$I_A^B(\mathbf{r}) = \int d\xi \Psi^*_{AI_AM_A}(\xi)\Psi_{BI_BM_B}(\mathbf{r}, \sigma_p, \xi), \tag{17}$$

where I_A and I_B are the total spins of nuclei A and B, respectively, and $\mathbf{r}$ is the position of the proton with respect to the c.m. of nucleus A. σ_p is the spin variable of the proton, and ξ stands for the remaining set of internal variables which also include isospins. Equation (17) also involves an antisymmetrization factor which is not shown here for the sake of simplicity. In this expression nuclear wave functions Ψ_A and Ψ_B are supposed to be properly translational invariant. The Hartree-Fock wave functions calculated in the preceding section may not be so despite the fact that a c.m. correction factor $E_{\mathrm{c.m.}}$ has been incorporated in the energy functional. Corrections for the spurious c.m. motion should, therefore, be applied to the HF wave functions before using them in Eq. (17). Effects of such corrections on the one-particle overlap function calculated within the shell model have been studied by several authors [38,39]. It is shown in Ref. [39] that this correction increases the one-particle overlap function (calculated with the shell model wave functions) in the asymptotic region (beyond 3 fm) by about 2–5% for lighter nuclei and even less than this for the medium mass ones. It is likely that the situation will be more or less the same for the HF case. In the following, we shall use the HF wave functions for ^{8}B and ^{7}Be as calculated in the preceding section to evaluate our one-particle overlap function with the understanding that conclusions drawn from this study may have an uncertainty of this rather small factor.

Equation (17) can be written more rigorously as

$$I_A^B(\mathbf{r}) = \sum_{\ell j \mu} \langle I_A M_A j m | I_B M_B \rangle \langle \ell m - \mu s \mu | j m \rangle i^\ell R^B_{A\ell j}(r) Y_{\ell m-\mu}(\hat{r}) \chi_{s\mu}, \tag{18}$$

where ℓ is the orbital angular momentum for the relative motion of proton with respect to nucleus A and s is the spin of the proton. Since the force parameter set TH1 is chosen to reproduce experimental one-proton separation energy in ^{8}B, the function $R^B_{A\ell j}(r)$ in Eq. (18) has the proper asymptotic behavior for this case. The same is not true for the parameter set TH2.

The overlap function for ^{8}B and ^{7}Be nuclei is used in the calculation of an asymptotic normalization constant which is related to the astrophysical factor S_{17}. It is also needed for the calculation of the valence proton density distribution which could be one more source of information about the existent of a proton halo structure in this nucleus. It should be noted that the overlap function is not an eigen function of the total Hamiltonian and it may or may not be normalized to unity.

The rms radius of the overlap function $R^B_{A\ell j}(r)$ corresponds to that of the ^{7}Be+p=^{8}B bound state (or of the valence proton) for a given ℓj combination. It can be written as

$$\langle r^2\rangle_{^7\mathrm{Be}-p} = N(0)^{-1}\int_0^\infty r^4 dr |R^B_{A\ell j}(r)|^2, \tag{19}$$

where

$$N(0) = \int_0^\infty r^2 dr |R^B_{A\ell j}(r)|^2. \tag{20}$$

Using HF wave functions calculated in the previous sections we get $\langle r^2\rangle^{1/2}_{^7\mathrm{Be}-p}$=4.76 fm. Comparing our results with those of other authors (as listed in Table I of Ref. [11]) we note that our results are in agreement with them within 10–20%. Thus, almost all these calculations appear to be in agreement with the fact that the valence proton has a large spatial extension in ^{8}B. One exception, however, is Ref. [40] where a relatively smaller value of 3.75 fm has been reported for the valence proton rms radius in ^{8}B. These authors have done their calculations by employing a two-body model with a Gaussian potential of range 1.90 fm which may not describe accurately the tail of the p-shell single-proton wave function in ^{8}B.

We have estimated the contribution of the asymptotic part of the overlap wave function to the valence proton rms radius in ^{8}B in the following way (see, e.g., Ref. [11]). We define the ratio

$$C_1(R_{cut}) = \frac{\int_{R_{cut}}^\infty r^2 dr |R^B_{A\ell j}(r)|^2}{\int_0^\infty r^2 dr |R^B_{A\ell j}(r)|^2}, \tag{21}$$

$$C_2(R_{cut}) = \frac{N(R_{cut})^{-1}\int_{R_{cut}}^\infty r^4 dr |R^B_{A\ell j}(r)|^2}{N(0)^{-1}\int_0^\infty r^4 dr |R^B_{A\ell j}(r)|^2}, \tag{22}$$

where R_{cut} is a cutoff radius and $N(x)$ is as defined in Eq. (20) with x being the lower limit of the integration. C_1 and C_2 give contributions of the asymptotic part to the norm of the overlap function and to the rms radius of the valence proton, respectively. For R_{cut}=2.5 fm which is the calculated value of the matter radius in ^{7}Be (see Table II), we find $C_1(R_{cut})[C_2(R_{cut})]$=0.62(0.87). This indicates that the region outside the ^{7}Be core contributes up to 87% to the valence proton radius in ^{8}B and that the probability of finding a valence proton outside the ^{7}Be core nucleus is about 62%. For R_{cut}=4.0 fm (beyond which the nuclear interaction becomes negligible) we get $C_1(R_{cut})[C_2(R_{cut})]$ =0.32(0.65). This means that contributions to the valence proton rms radius are about 65% from the distances beyond 4 fm. These results provide further support to the existence of a proton halo structure in the ^{8}B nucleus. As remarked earlier, in these calculations we have assumed that ^{7}Be behaves as an inert core inside the ^{8}B nucleus. Consideration of the excitation of ^{7}Be core will not change these conclusions significantly [11,41].

TABLE III. SkHF results for asymptotic normalization coefficients $\bar{c}_{\ell j}$, and astrophysical S factors $S^A_{17}(0)$, $S^B_{17}(0)$, and $S^C_{17}(0)$. S^A_{17} corresponds to results obtained by using the HF overlap function directly to a capture code while S^B_{17} and S^C_{17} corresponds to those obtained by using Eq. (25) with κ=36.5 and 37.8, respectively.

	SkHF	
	TH1	TH2
$\bar{c}_{13/2}$	0.64	0.88
$\bar{c}_{11/2}$	0.34	0.29
$S^A_{17}(0)$(eV b)	22.0	35.3
$S^B_{17}(0)$(eV b)	19.5	31.3
$S^C_{17}(0)$(eV b)	20.2	32.4

It may be mentioned here that the experimental value of the quadrupole moment of ^{8}B (which is twice as large as the value predicted by the shell model) can be explained with a single-particle wave function corresponding to a matter radius of 2.72 fm [36,35]. This observation has been thought of as a possible evidence for a proton halo structure in ^{8}B. The matter radius of this nucleus as calculated by our model is very close to the above value.

Next, we present results for the astrophysical S_{17} factor calculated within our model. In the region outside the core where range of the nuclear interaction becomes negligible (r>4.0 fm), the radial overlap wave function $R(r)$ of the bound state can be written as

$$R^B_{A\ell j}(r) \simeq \bar{c}_{lj} W_{\eta,l+1/2}(2kr)/r, \tag{23}$$

where W is the Whittaker function, k the wave number corresponding to the single-proton separation energy, and η the Sommerfield parameter for the bound state in ^{8}B. In Eq. (23), $\bar{c}_{lj}$ is the asymptotic normalization constant, required to normalize the radial overlap wave function in the ^{8}B nucleus to the Whittaker function in the asymptotic region. The S_{17} factor is related to the proton capture cross section as

$$S_{17}(E) = \sigma(E)E\ e^{[2\pi\eta(E)]}. \tag{24}$$

It has been shown in Ref. [16] that at the zero energy the S_{17} factor depends only on $c_{\bar{l}j}$ and one can write [21,22]

$$S_{17}(0) = \kappa \sum_j \bar{c}^2_{1j}. \tag{25}$$

In Ref. [21], κ(=37.8) has been obtained by using a microscopic cluster model for the scattering states, while a value of 36.5 has been reported for this quantity in Ref. [22] using a hard sphere scattering state model. However, it has been argued in Ref. [21] that once the relevant integration distances are sufficiently enhanced in Ref. [22] the value of κ there comes out to be 37.2, which is in good agreement with that of the microscopic model.

In our calculations, we have used our HF overlap function directly as an input to a capture code where the scattering states are described by pure Coulomb wave functions between ^{7}Be and p. Thus, within an inert ^{7}Be core approximation our results are parameter-free. In Table III, $S^A_{17}(0)$ represents the astrophysical S factor obtained by this method. We show results obtained by using overlap functions calculated with both TH1 and TH2 force parameters. We see that $S_{17}^{A}(0)$ obtained with TH1 force is quite close to its adopted value of $19.1^{+4.0}_{-1.0}$ eV b. On the other hand, that obtained with TH2 is quite large and well beyond the maximum limit of this value. We also show in this table values of asymptotic normalization coefficients and $S_{17}(0)$ obtained by using Eq. (25) with κ=36.5 and 37.8 [$S_{17}^{B}(0)$ and $S_{17}^{C}(0)$, respectively] These results are in agreement with those obtained by our method within 10%.

IV. SUMMARY AND CONCLUSIONS

In summary, in this paper we studied the structure of ^{8}Li, ^{8}B, ^{7}B, ^{7}Be, and ^{9}C nuclei within the Skyrme Hartree-Fock framework with SLy4 interaction parameters whose spin-orbit part is renormalized so as to reproduce the last proton binding energy in ^{8}B. The adjusted spin-orbit term is weaker than that of the original force. We calculated binding energies, various densities distribution, and rms radii for these nuclei. Using the same set of the force parameters, we obtain good agreements with experimental values of binding energies and rms matter radii for all these nuclei. We have calculated the overlap function $\langle ^7\mathrm{Be}|^8\mathrm{B}\rangle$ from the SkHF wave functions which has been employed to obtain the radius of the valence proton in ^{8}B nucleus. The value of this quantity is found to be 4.76 fm which is almost two times larger than the matter radius of ^{7}Be core. This provides support to the possibility of ^{8}B having a one-proton halo structure.

The same overlap function is used to extract the asymptotic normalization coefficients for $^8\mathrm{B}\rightarrow{}^7\mathrm{Be}+p$. Using the overlap function calculated with the modified force we obtain an astrophysical S-factor of 22.0 eV b while the original parametrization leads to a value of 35.0 eV b. Thus S_{17} calculated with the TH1 force lies within the adopted limits ($19.1^{+4.0}_{-1.0}$ eV b) of the near zero energy astrophysical S-factor. The values of S_{17} obtained by using the corresponding asymptotic normalization coefficients follow the similar trend. It may however be noted that the overlap functions calculated with HF wave functions may have some uncertainties coming from the fact that these wave functions may not be properly translational invariant. Work is in progress to improve our calculations in this regard.

The results of our calculations have a strong dependence on the parameter of the spin-orbit term of the Skyrme interaction. This suggests that it may be possible to have some important clue about the effective interaction in drip line nuclei from the comparison of calculations with some experimental observables.

ACKNOWLEDGMENT

This work was supported by the Department of Atomic Energy, BRNS, BARC, Mumbai, under Contract No. 2001/37/14/BRNS/699.

[1] I. Tanihata *et al.*, Phys. Rev. Lett. **55**, 2676 (1985); Prog. Part. Nucl. Phys. **35**, 505 (1995); J. Phys. G **22**, 157 (1996).
[2] I. Tanihata, T. Kobayashi, O. Yamakawa, S. Shimoura, K. Ekuni, K. Sugimoto, N. Takashi, T. Shimoda, and H. Sato, Phys. Lett. B **206**, 592 (1988).
[3] P. G. Hansen, A. S. Jensen, and B. Jonson, Annu. Rev. Nucl. Part. Sci. **45**, 591 (1995).
[4] J. N. Bachcall, *Neutrino Astrophysics* (Cambridge University Press, Cambridge, 1989); J. N. Bachall and M. Pinsonneault, Rev. Mod. Phys. **64**, 885 (1992).
[5] R. Davis, Prog. Part. Nucl. Phys. **32**, 13 (1994); Eric G. Adelberger *et al.*, Rev. Mod. Phys. **70**, 1265 (1998).
[6] S. Fukuda *et al.*, Phys. Rev. Lett. **86**, 5651 (2001); Q. R. Ahmad *et al.*, *ibid.* **87**, 071031 (2001); **89**, 011301 (2002).
[7] H. Esbensen and K. Hencken, Phys. Rev. C **61**, 054606 (2000).
[8] T. Barker *et al.*, Phys. Rep. **289**, 235 (1997).
[9] R. Shyam and H. Lenske, Phys. Rev. C **57**, 2427 (1998).
[10] N. K. Timofeyuk, Nucl. Phys. **A632**, 19 (1998).
[11] F. Carstoiu, L. Trache, C. A. Gagliardi, R. E. Tribble, and A. M. Mukhamedzhanov, Phys. Rev. C **63**, 054310 (2001).
[12] M. H. Simedberg *et al.*, Phys. Lett. B **452**, 1 (1999).
[13] L. V. Grigorenko, B. V. Danilin, V. D. Efros, N. B. Shulgina, and M. M. Zhukov, Phys. Rev. C **57**, 2099(R) (1998).
[14] B. W. Fillippone, S. J. Elwyn, C. N. Davids, and D. D. Koetke, Phys. Rev. Lett. **50**, 412 (1983); Phys. Rev. C **28**, 2222 (1983); F. Hammache *et al.*, Phys. Rev. Lett. **80**, 928 (1998); A. R. Junghans *et al.*, *ibid.* **88**, 041101 (2002).
[15] T. Motobayashi *et al.*, Phys. Rev. Lett. **73**, 2680 (1994); T. Motobayashi, Nucl. Phys. **A693**, 258 (2001); N. Iwasa *et al.*, Phys. Rev. Lett. **83**, 2910 (1999); B. Davids *et al.*, Phys. Rev. C **63**, 065806 (2001).
[16] H. M. Xu, C. A. Gagliardi, R. E. Tribble, A M. Mukhamedzhanov, and N. K. Timofeyuk, Phys. Rev. Lett. **73**, 2027 (1994).
[17] G. A. Gagliardi *et al.*, Nucl. Phys. **A682**, 369 (2001).
[18] A. Azhari *et al.*, Phys. Rev. C **60**, 055803 (1999).
[19] W. Lui *et al.*, Nucl. Phys. **A616**, 131C (1997); Phys. Rev. Lett. **77**, 611 (1996).
[20] N. K. Timofeyuk, D. Baye, and P. Descouvemint, Nucl. Phys. **A620**, 29 (1997).
[21] A. Csoto, Phys. Rev. C **61**, 037601 (2000); B. K. Jennings, S. Karataglidis, and T. D. Shoppa, *ibid.* **58**, 3711 (1998).
[22] B. A. Brown, A. Costo, and R. Sherr, Nucl. Phys. **A597**, 66 (1996).
[23] J. W. Negele and D. Vautherin, Phys. Rev. C **5**, 1472 (1972).
[24] F. Quentin and H. Flocard, Annu. Rev. Nucl. Part. Sci. **28**, 523 (1978).
[25] J. Friedrich and P.-G. Rienhard, Phys. Rev. C **33**, 335 (1986).
[26] J. Dobaczewski, I. Hamamoto, W. Nazarewicz, and J. A. Sheikh, Phys. Rev. Lett. **72**, 981 (1994).
[27] Yao-song Shen and Zhogzhon Ren, Phys. Rev. C **54**, 1158

(1996).
[28] X. Li and P. H. Heensen, Phys. Rev. C **54**, 1617 (1996).
[29] S. Mizutori, J. Dobaczewski, G. A. Lalazissis, W. Nazarewicz, and P. G. Reinhard, Phys. Rev. C **61**, 044326 (2000).
[30] P. G. Reinhard, D. J. Dean, W. Nazarewicz, J. Dobaczewski, J. A. Maruhn, and M. R. Strayer, Phys. Rev. C **60**, 014316 (1999).
[31] E. Chabanat, P. Bonche, P. Haensel, J. Meyey, and R. Schaeffer, Nucl. Phys. **A627**, 710 (1997).
[32] P. G. Reinhard, *Computational Nuclear Physics 1* (Springer, Berlin, 1991), p. 28.
[33] G. A. Lalazissis, D. Vretenar, W. Pöschl, and P. Ring, Phys. Lett. B **418**, 7 (1998).
[34] R. B. Firestone, V. S. Shirley, C. M. Bagln, S. Y.E. Chu, and J. Zipkin, *Table of Isotopes* (Wiley, New York, 1996).
[35] M. M. Obut *et al.*, Nucl. Phys. **A609**, 74 (1996); R. E. Warner *et al.*, Phys. Rev. C **52**, R1166 (1995).
[36] F. Negoita *et al.*, Phys. Rev. C **54**, 1787 (1996).
[37] A. Ozawa *et al.*, Nucl. Phys. **A608**, 63 (1996).
[38] W. T. Pinkston, Nucl. Phys. **A269**, 281 (1976); W. T. Pinkston and P. J. Iano, *ibid.* **A330**, 91 (1979).
[39] R. Shyam and M. A. Nagarajan, J. Phys. G **9**, 901 (1983).
[40] K. Riisager and J. S. Jensen, Phys. Lett. B **301**, 6 (1993).
[41] A. M. Moro, R. Crespo, F. Nunes, and I. J. Thompson, Phys. Rev. C **66**, 024612 (2002).